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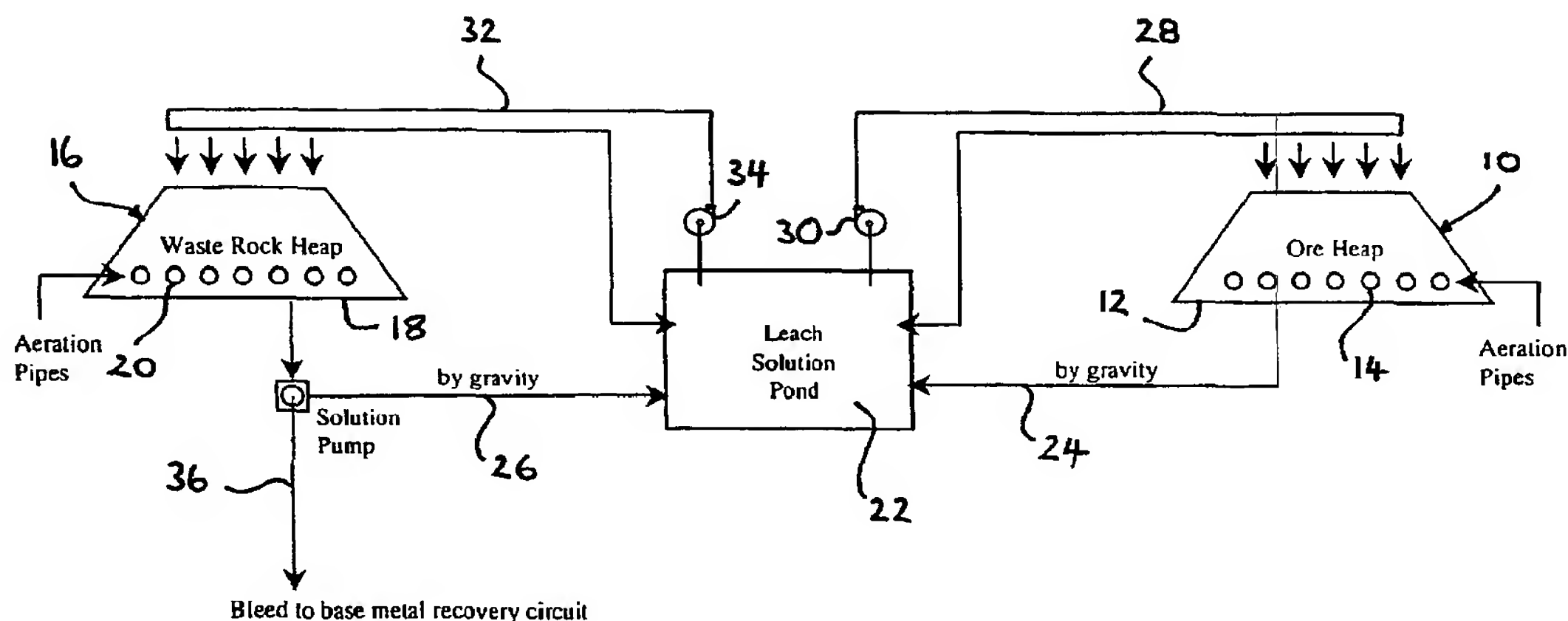
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(54) Title: A BACTERIALLY ASSISTED HEAP LEACH



(57) Abstract: A bacterially assisted heap leach characterised by the steps of: providing an ore heap to oxidise sulphide minerals therein; providing a biological contactor inoculated with ferrous iron oxidising bacteria; providing at least one leach solution pond to feed solution to, and receive leach solution from both the heaps; and bleeding a portion of the leach solution and passing same to a means for metals recovery.



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**“A Bacterially Assisted Heap Leach”****Field of the Invention**

The present invention relates to a bacterially assisted heap leach. More particularly, the bacterially assisted heap leach of the present invention is  
5 intended for use in the recovery of nickel and associated base metals from sulphide ores.

**Background Art**

The recovery of base metals from sulphide ores by bacterially assisted heap leaching is presently restricted to secondary copper sulphide minerals, such as  
10 chalcocite and covellite. Chalcopyrite, a primary copper sulphide mineral, is a notable exception and can not presently be successfully leached in a heap. There is currently no proven method available for the successful bacterially assisted heap leaching of nickel sulphides, zinc sulphides or any other base metal sulphide except those of copper, excluding chalcopyrite.

15 The bacterially assisted heap leach of the present invention has as one object thereof to overcome the problems associated with the prior art, or to at least provide a useful alternative thereto.

The preceding discussion of the background art is intended to facilitate an understanding of the present invention only. It should be appreciated that the  
20 discussion is not an acknowledgement or admission that any of the material referred to was part of the common general knowledge in Australia as at the priority date of the application.

Throughout this specification, unless the context requires otherwise, the word “comprise”, or variations such as “comprises” or “comprising”, will be understood  
25 to imply the inclusion of a stated integer or group of integers but not the exclusion of any other integer or group of integers.

## Disclosure of the Invention

In accordance with the present invention there is provided a bacterially assisted heap leach characterized by the steps of:

- providing an ore heap to oxidise sulphide minerals therein;
- 5       providing a biological contactor inoculated with ferrous iron oxidising bacteria;
- providing at least one leach solution pond to feed solution to, and receive leach solution from both the heaps; and
- bleeding a portion of the leach solution and passing same to a means for  
10       metals recovery.

Preferably, one or both of the heaps are aerated at or near a base thereof.

Still preferably, the biological contactor is provided in the form of a second heap.

The second heap is preferably formed of relatively inert waste rock. The second heap may be inoculated with *Thiobacillus ferrooxidans* or similar bacteria.

- 15       The bled portion of leach solution is preferably taken from the second heap.

In accordance with the present invention there is further provided a process for the recovery of nickel and other base metals from sulphide ores or fractions thereof, the process characterized by the steps of:

- oxidising the sulphide ore in a heap leach to produce a leach solution; and
- 20       oxidising any ferrous iron in the leach solution from the heap leach prior to recovery of base metals therefrom.

The oxidation of the sulphide ore or fraction thereof is preferably achieved through the action of chemolithotrophic bacteria.

The oxidation of ferrous iron in the leach solution is preferably achieved by passing same through a further heap inoculated with an iron oxidising bacteria.

- 5 The iron oxidising bacteria may be *Thiobacillus ferrooxidans*.

### Brief Description of the Drawings

The present invention will now be described, by way of example only, with reference to two embodiments thereof and the accompanying drawings, in which:

10 Figure 1 is a schematic representation or flow sheet of a bacterially assisted heap leach in accordance with a first embodiment of the present invention;

Figure 2 is a schematic representation or flow sheet of a bacterially assisted heap leach in accordance with a second embodiment of the present invention;

15 Figure 3 is a graphical representation of the size distributions of pulverized ore samples of Example I;

Figure 4 is a graphical representation of the mass of ferric, ferrous and total iron within the leach solution pond over time for Example III; and

20 Figure 5 is a graphical representation of the rate of nickel leaching from the leach heap of Example III.

### Best Mode(s) for Carrying Out the Invention

In Figure 1 there is shown a flow sheet for the bacterially assisted heap leaching of a whole ore or a fraction thereof, by the action of chemolithotrophic bacteria, in accordance with a first embodiment of the present invention. A disseminated  
25 sulphide ore is stacked in a heap 10 on an impermeable leach pad 12. It is

envisaged that the disseminated sulphide ore may have undergone one or more pre-treatments, for example agglomeration, to improve its permeability, or some form of upgrading step to improve its base metal content.

5 The heap 10 has slotted aeration pipes 14 inserted into a base of the heap 10 to provide a source of oxygen and carbon to the bacteria present in the disseminated sulphide ore. These bacteria are encouraged to multiply and populate the heap, and consequently oxidise the sulphide minerals.

10 It is envisaged that the process of the present invention may require a different bacterial species to populate the heap and such a species would have to be introduced thereto by way of inoculation. This may be achieved by adding a solution containing the preferred bacteria to the material to be treated before, during or after stacking of the heap 10.

15 A biological contactor, for example a second heap 16 formed of a relatively inert waste rock is provided on a further impermeable leach pad 18. The second heap 16 is similarly provided with slotted aeration pipes 20 near the base thereof. The heap 16 is inoculated with ferrous iron oxidising bacteria, for example *Thiobacillus ferrooxidans*, which may or may not be indigenous to the heap 16.

20 A leach solution pond 22 is provided and receives leach solution from the heaps 10 and 16 by way of gravity feed lines 24 and 26, respectively. The heap 10 receives leach solution from the pond 22 by way of feed line 28 in which is provided a pump 30. Any leach solution not fed to the heap 10 is returned to the pond 22.

25 The heap 16 receives leach solution from the pond 22 by way of feed line 32, in which is provided a pump 34. Any leach solution not fed to the heap 16 is returned to the pond 22.

The delivery of leach solution to the heaps 10 and 16 preferably delivers a consistent and even distribution of leach solution to the top and sides of each heap 10 and 16. A bleed line 36 is provided in the gravity feed line 26 from the

heap 16 and is used to bleed leach solution, now being deficient in ferrous iron when compared to the leach solution in the pond 22, out of the circuit shown in Figure 1 and into a means for metals recovery. Conventional hydrometallurgical means may then be used to recover the base metals from this leach solution.

- 5 It is envisaged that the heating or cooling of the leach solution at some point in the flow sheet shown in Figure 1 may prove advantageous.

The biological contactor may, it is envisaged, alternately be provided in the form of a packed column or rotating biological contactor.

- 10 In Figure 2 there is shown a flow sheet for the bacterially assisted heap leaching of a whole ore or a fraction thereof, by the action of chemolithotrophic bacteria, in accordance with a second embodiment of the present invention. The flow sheet is substantially similar to that of the first embodiment shown in Figure 1 and like numerals denote like components.

- 15 The leach solution pond 22 of the first embodiment is replaced by two ponds, being an inert rock pond 40 and an ore pond 42. The ore pond 42 receives leach solution from the heap 10 by way of gravity feed line 44. The heap 10 receives leach solution from the pond 42 by way of the feed line 28. Any leach solution not fed to the heap 10 is returned to the pond 42.

- 20 The heap 16 received leach solution from the inert rock pond 40 by way of the feed line 32. Any leach solution not fed to the heap 16 is returned to the pond 40. The pond 40 receives leach solution from the heap 16 by way of a gravity feed line 45 in which is provided a pump 48.

- 25 Overflow from the inert rock pond 40 is directed to the ore pond 42 by way of an overflow line 50. Liquor from the ore pond 42 is, in addition to being fed to the heap 10, fed to the heap 16 by way of intermediate line 52 and the feed line 32.

A bleed line 52 is provided in the gravity feed line 46 from the heap 16 and is used to bleed leach solution now deficient in ferrous iron when compared to the leach



solution of pond 42, out of the circuit shown in Figure 2 and into a means for metals recovery. Again, conventional hydrometallurgical means may then be used to recover the base metals from this leach solution.

5 The use of separate ponds 40 and 42 is envisaged to allow greater flexibility in the circuit than possible with that of Figure 1. For example, the heaps of the second embodiment may be run under differing conditions as to pH and ferrous to ferric iron ratio.

10 It is further envisaged that the leach solution may preferably be recycled through each heap 10 and 16 more than once in order to increase the level of dissolved metals. Further, some form of pH control may prove advantageous.

15 It is still further envisaged that some or all of the ferric iron in the leach solution may advantageously be precipitated by a process of hydration, whereby a jarosite or a goethite product is formed and an acid, usually sulphuric acid, is also formed. This may be encouraged to take place remotely to the heap 10, for example in the heap 16.

20 The process of the present invention provides for the economic recovery of nickel and other base metal sulphides, for example cobalt and zinc, from their ores. It is envisaged that the capital and operating costs of base metals production by the process of the present invention will compare favourably with conventional recovery processes. Still further, it is envisaged that the process can be applied to mineral deposits of lower base metal value than would typically be economically viable using conventional or prior art methods.

25 The present invention will now be described with reference to a number of examples. However, it is to be understood that the following examples are not to limit the above generality of the invention.

Example I

A bench scale mini-pilot column operation was conducted in an effort to optimise operating conditions for a heap leach in accordance with the first embodiment of the present invention.

A 500 kg bulk sample of a disseminated ore sample from the Radio Hill deposit in Western Australia, Australia was utilised in this example. The sample was air dried prior to crushing, blending and splitting into sub-samples for head assay, inoculum generation, bioleach optimization and the mini-pilot trial. The disseminated ore is known to contain approximately 0.92% Cu, 0.67% Ni, and 0.34% Co.

The sub-samples were pulverized and assayed for  $\text{CO}_3^{2-}$ , total S, and 31 elements by ICPMS. Size distribution of the samples was carried out using various sieve sizes to 38 $\mu\text{m}$ . Each fraction from the size analysis was assayed for Ni and Cu content. The size distribution and chemical assay of the various fractions are shown in Table 2 and in Figure 1.

**Table 1**  
**Chemical Assay Results**

Element	Concentration (mg/Kg)	Element	Concentration (mg/Kg)
Aluminum	23000	Molybdenum	16.2
Antimony	2.4	Nickel	6670
Arsenic	12	Potassium	3760
Barium	222	Rubidium	4.5
Beryllium	0.4	Selenium	7
Bismuth	2	Silver	5.3
Boron	< 1	Sodium	14700
Cadmium	2.1	Strontium	113
Calcium	60100	Sulphur	4.05
Chromium	476	Tellurium	1.1
Cobalt	336	Thallium	< 0.1
Copper	9230	Tin	12.2
Iron	111000	Uranium	0.3
Lead	34.8	Vanadium	173
Lithium	12.4	Zinc	203
Magnesium	40400	$\text{CO}_3^{2-}$	< 0.5
Manganese	1520		



**Table 2****Sieve and Chemical Analysis on RH Disseminated Ore Head**

<b>Sieve #</b>	<b>Mass</b>		<b>Cumulative</b>	<b>Cu</b>	<b>Ni</b>
<b>(mesh)</b>	<b>Retained</b>		<b>% Passing</b>	<b>(%)</b>	<b>(%)</b>
	<b>(g)</b>	<b>% Retaining</b>			
4	0	0	100.0		
-4 +6	344	34.37	65.6	0.84	0.60
-6 +10	295	29.47	36.2	0.90	0.60
-10 +18	139	13.89	22.3	0.89	0.58
-18 +30	53	5.29	17.0	0.89	0.55
-30 +45	42	4.20	12.8	0.94	0.60
-45 +80	42	4.20	8.6	0.98	0.70
-80 +100	9	0.90	7.7	1.08	0.96
-100 +200	21	2.10	5.6	1.25	1.26
-200	56	5.59	-	1.79	1.45

Initial hot nitric acid leach tests on various grind sizes were conducted to  
5 determined the optimum size range for the Radio Hill disseminated ore. It was  
determined that a 4 mesh grind size (4.76 mm) would be required to have  
sufficient exposure of the mineralization for the leach. If the fines content,  
generated through crushing is excessively high then agglomeration is typically  
used for coarsening to prevent potential flooding during the leaching period. A  
10 3.5 kg -4 mesh crushed ore sample was prepared and loaded into a 3" plastic  
column. Acidified water was pumped and sprayed into the column to establish the  
maximum percolation rate before flooding takes place. The percolating test  
results are shown in Table 3 below:

**Table 3**  
**Percolation Tests on Radio Hill Disseminated Ore**

Column:	3" diameter
Ore Loaded:	3.5 kg ( 100% -4.76mm)
Ore Height:	17.75"
Water pattern:	spray
Critical Flow Rate:	492 ml/min
Area of Column	0.00145 m <sup>2</sup>
Flow Rate:	0.20359 L/hr/m <sup>2</sup>
Flow Rate	Observation
(ml/min)	
155	OK
230	OK
385	OK
405	OK
460	OK
485	OK
520	Flooded
495	Flooded
420	OK
435	OK
495	Flooded
492	Flood Point

- 5 Tests were carried out to optimize the leach culture selection and operating conditions. The tests were carried out with various cultures, temperature conditions, pH and finally nutrient addition. The test matrix used to optimize the chalcopyrite culture as well as the indigenous culture for metals extraction is summarized in Table 4 below:

10

Each test was carried out in 5 litre aerated reactor vessels. A 3 litre portion of the prepared inoculum and 300 grams of the ore sample was added to each vessel. The tanks were agitated at a rate sufficient to keep the solids suspended (450-500 rpm). The tanks were monitored for dissolved oxygen (DO), pH, oxidation

15 reduction potential (ORP),  $\text{Fe}^{2+}$ ,  $\text{Fe}^{3+}$ ,  $\text{Fe}^{\text{total}}$ , as required. Acid was added to maintain the desired pH. Solution samples were removed from the tanks, filtered and solids were returned to the leach tanks.

Solution samples were assayed by atomic absorption spectroscopy (AAS) for

20 metal concentration. Final leach residues were assayed for Ni, Co, Cu, Fe, and S, after washing with dilute  $\text{H}_2\text{SO}_4$  and drying. Preliminary optimization test

results are shown in Table 5 below. Extractions of >90% Cu and Ni were attainable within 14 - 22 days using the applicant's (POT) inoculum, at temperatures of 50 - 60°C and pH of 1 - 1.8. Co extractions behaved in a similar manner although extractions were somewhat less at >85%.

5

**Table 4**  
**Optimization Test Matrix**

Test	Innoculum	Temp.	pH	Nutrient (g/l)				
#		(°C)		(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	K <sub>2</sub> HPO <sub>4</sub>	MgSO <sub>4</sub> * 7H <sub>2</sub> O	H <sub>3</sub> PO <sub>4</sub>	H <sub>2</sub> SO <sub>4</sub>
1	Radio Hill	40	1.0	1.0	0.5	0.16		2.0
2	POT	40	1.0	1.0	0.5	0.16		2.0
3	Radio Hill	45	1.0	1.0	0.5	0.16		2.0
4	POT	45	1.0	1.0	0.5	0.16		2.0
5	Radio Hill	50	1.0	1.0	0.5	0.16		2.0
6	POT	50	1.0	1.0	0.5	0.16		2.0
7	Radio Hill	55	1.0	1.0	0.5	0.16		2.0
8	POT	55	1.0	1.0	0.5	0.16		2.0
9	Radio Hill	60	1.0	1.0	0.5	0.16		2.0
10	POT	60	1.0	1.0	0.5	0.16		2.0
11	POT	60	0.8	1.0	0.5	0.16		2.0
12	POT	60	1.0	1.0	0.5	0.16		2.0
13	POT	60	1.4	1.0	0.5	0.16		2.0
14	POT	60	1.8	1.0	0.5	0.16		2.0
15	POT	60	2.2	1.0	0.5	0.16		2.0
16	POT	60	1.4	1.0	0.5	0.16		2.0
17	POT	60	1.4	0.5	0.25	0.08		2.0
18	POT	60	1.4	0.3	0.16	0.053		2.0
19	POT	60	1.4	1.0	0.0	0.0	0.331	2.0
20	POT	60	1.4	1.0	0.0	0.0		2.0
				(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	K <sub>2</sub> HPO <sub>4</sub>	(NH <sub>4</sub> ) <sub>2</sub> HPO <sub>4</sub>	K <sub>2</sub> SO <sub>4</sub>	H <sub>2</sub> SO <sub>4</sub>
21	POT	60	1.4	1.0	0.5	0.0	0.0	2.0
22	POT	60	1.4	0.0	0.0	0.38	0.5	2.0
23	POT	60	1.4	0.0	0.0	0.38	0.0	2.0
24	POT	60	1.4	0.0	0.0	0.61	0.5	2.0
25	POT	60	1.4	Ferric Leach				
26	POT	60	1.4	Test 21 Conditions - Bioleach of Test 25 residue				

**Table 5**  
**Optimization Test Results**

Test #	Bacteria	Tem p	Nutrien t	PH	R.T.	Cu	Fe	Ni	Co	S
		(°C)			(Days)	(%)	(%)	(%)	(%)	(%)
1	Radio	40	0k Base	1	8	31.4	62.2	48.6	47.4	36
2	POT	40	0k Base	1	8	31.8	50.7	37.5	41.6	11.5
3	Radio	45	0k Base	1	12	15.6	47.1	53.7	56.3	1.8
4	POT	45	0k Base	1	12	59	66.7	66.6	69.4	36.8
5	Radio	50	0k Base	1	8	19.7	51	49.3	45.2	8.9
6	POT	50	0k Base	1	8	97.3	62.1	51.6	55.9	21.6
7	Radio	55	0k Base	1	14	63.7	67.8	83.5	85.2	43.9
8	POT	55	0k Base	1	14	98.3	94.6	88.4	90.7	27.9
9	Radio	60	0k Base	1	9	53	57.5	71.2	79.7	8.1
10	POT	60	0k Base	1	9	97.8	59.6	76.9	75.9	13.4
11	POT	60	0k Base	0.8	9	39.6	53.1	74.8	67.1	-9
					22	95.4	65.6	94	87.8	24.1
12	POT	60	0k Base	1	9	38.3	54.1	76.3	72	-6.2
					22	97.4	62.5	94.2	88	15.4
13	POT	60	0k Base	1.4	9	61.1	38.4	73.3	69.2	6.9
					22	96.1	54.2	94.1	87	19.9
14	POT	60	0k Base	1.8	9	85.2	24.3	66.5	60.7	11.6
					22	91.8	30.7	94.6	87.1	-15.1
15	POT	60	0k Base	2.2	9	50.7	3.5	58	50	-21.3
					22	81.7	11.5	91.4	83	-14
16	POT	60	Table 3	1.4	17	88.7	47.2	91.1	86.1	9.3
17	POT	60	Table 3	1.4	17	82.8	53.3	91.7	86.3	31.3
18	POT	60	Table 3	1.4	17	91.1	53.9	91.5	84.7	29.3
19	POT	60	Table 3	1.4	17	97.2	56.7	91.1	85.3	25.9
20	POT	60	Table 3	1.4	17	77	54.5	90.5	84.4	31.7
21	POT	60	Table 3	1.4	14	90.2	7.5	89.2	84.3	10.7
22	POT	60	Table 3	1.4	14	89.4	15.6	89.1	83.1	31
23	POT	60	Table 3	1.4	14	92	26	88.4	83.7	19.2
24	POT	60	Table 3	1.4	14	83.2	8.9	87.9	80.8	-10.3
25	POT	60	Table 3	1.4	23	79.6	Ferric Leach - Stage 1			
26	POT	60	Table 3	1.4	Bioleach on Ferric Leach Residue - Stage 2					

A total of 7 leach columns were setup and operated. Each column was loaded with approximately 3 kg of the sample. Leach columns were heated to control the desired operating temperature. The inoculum was sprayed from the top onto the columns to allow percolation through the test sample. Leach solution was collected in heated holding tanks (pond). Air was delivered through a distributor for proper column and holding tank aeration. The leach solution was monitored for DO, pH, ORP,  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$ . Acid was added as required to maintain the desired pH. Solution samples were taken on a weekly basis. The solution

samples were assayed for Ni, Cu, Co and Fe. The columns were operated from 63 to 208 days.

A summary of the operating conditions and final extraction results for the 9 columns are shown in Table 6 below. The optimum column leach results were attained at pH 1.4 and 50°C (Test 6) where approximately 80% metal extraction was achieved after 52 days of operation. A pH of 1.8 was actually selected for the pilot scale operating conditions to reduce acid consumption (0.1 tonne acid/tonne ore @ pH 1.8 as opposed to 0.2 tonne acid/tonne ore @ pH 1.4).

10

**Table 6**  
**Column Test Conditions and Leach Extraction**

Test #	Description	Temp. (°C)	pH	Acid/Ore	Acid Wash	R.T. (Days)	Fe (%)	Cu (%)	Ni (%)	Co (%)	S (%)
1	downflow	45	1.5	0.174	No	97	15.1	21.7	68.2	63.7	-
				0.203		163	44.5	46.2	90	80	0.7
2	upflow	45	1	0.244	No	63	30.8	75.8	58	51.3	11
3	downflow	60	1.4	0.190	No	72	22.9	53.2	83	77.6	0.6
				0.249		163	47.3	67.6	93	83.4	-8
5	downflow	60	1.4	0.179	Yes	34	26.0	69.3	83.8	75.0	3.3
				0.212		79	32.1	75.9	91.4	84.8	9.5
6	downflow	50	1.4	0.193	Yes	52	26.1	80.5	79.7	72.5	4.8
				0.205		94	33.0	82.8	86.6	79.0	17.2
7	downflow	50	1.8	0.105	Yes	52	8.0	62.0	79.7	71.2	4.0
				0.106		93	18.2	68.4	85.8	78.0	6.3
9	downflow	45	1.4	0.159	Yes	59	32.2	53.2	79.6	71.5	7.5
				0.170		105	32.4	54.3	85.6	77.7	17.9

Columns 4 and 8 were carried out to investigate ferric regeneration and iron precipitation tests, respectively, as a separate process step outside the heap as process enhancements. The columns (3" diameter x 3' high) were loaded with approximately 3 kg of inert ceramic saddle substrate crushed to minus 1/4". Solution was pumped to the top and percolated at a rate of 100 ml/min through the columns. The solution was collected into a 5 litre container and recycled back to the column. In Test 4 the ORP was checked on a regular basis and when the solution reached 600 mV additional ferrous iron as  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  was added. The

20

cycle was maintained over 41/2 months, adding ferrous about every 2 to 4 days based on the ORP and the initial 30 days is presented in Table 7.

5

**Table 7**  
**Ferric Regeneration Test (Column 4)**

Day	ORP	FeSO <sub>4</sub> ·7H <sub>2</sub> O (g)	Fe <sup>2+</sup> (g)	Day	ORP (mV)	FeSO <sub>4</sub> ·7H <sub>2</sub> O (g)	Fe <sup>2+</sup> (g)
0	624	15	3	16	612	15	3
	504				501		
1	526			17	553		
2	590			18	622	7.5	1.5
3	612	15	3		522		
	506			19	613	7.5	1.5
4	534				544		
5	609	15	3	20	616	7.5	1.5
	501				539		
6	510			21	591		
7	561			22	627	30	6
8	617	15	3		490		
	501			23	520		
9	534			24	564		
10	608	15	3	25	623	45	9
	503				473		
11	547			26	502		
12	624	15	3	27	515		
	512			28	541		
13	551			29	599		
14	608	15	3	30	607		
	497			Total (g)		217.5	43.7
15	548			Total (g/day)		7.25	1.46

The ferrous regeneration column using 3 kg of substrate converted an average of 1.46 g/day of ferrous to ferric, and ranged up to 2 g/day. Based on this data, it is expected that it will take 1/4 tonne of inert waste rock to treat the pregnant solution from a 1 tonne ore heap.

Test 8 was carried out to investigate control of both the Na and Fe levels in solution by acting to enhance jarosite precipitation. In the heap leach of the present invention it is envisaged that calcium carbonate will be used to precipitate iron and Na<sub>2</sub>CO<sub>3</sub> will be used to precipitate the remaining base metals as carbonates. The filtrate containing sodium sulphate can then be used to precipitate out sodium jarosite. This effectively prevents cation build up, takes



iron out of the leach circuit and produces acid at the same time. It is envisaged that Jarosite formation will be sufficient in practice using aerated waste rock heaps. Preliminary results are shown in Table 8 below:

5

**Table 8**  
**Jarosite Precipitation Column (Test 8)**

Day	ORP	Fe <sup>++</sup> (g/l)	Fe <sup>+++</sup> (g/l)	Fe <sup>Tot</sup> (g/l)	Na (g/l)	Comment
79	480	1.96	11.04	13.00	3080	
86	701	0.17	14.83	15.00		
93	683	0.22	14.38	14.60	3070	pH adjust 1.10 to 1.83 with NaOH
102	401			12.50	5810	
107	416	5.59	5.01	10.60	5620	
114	671	3.91	6.29	10.20	5080	
123	444	0.84	7.05	7.89	4980	
128	680	0.45	7.48	7.93	4190	add 30 g Fe <sub>2</sub> SO <sub>4</sub> ·7H <sub>2</sub> O
135	664	0.119	8.49	8.61	4790	

Initial results from the jarosite precipitation testing are positive. Reference to the column from between 79 to 135 shows a gradual decrease in total Fe and sodium,  
10 indicative that jarosite precipitation is taking place.

#### Example II

A 4" diameter by 16' high column was set up for a pilot of a heap leach in  
15 accordance with the first embodiment of the present invention and Figure 1. The column was loaded with 60 kg of ore crushed to -4 mesh which had a total height of 15'. Prior to loading the ore was wetted using acidified water and thoroughly mixed to insure even distribution of fines. Acidified water was percolated through the column and acid was added as required for the initial 18 days to maintain pH  
20 1.8 before inoculum was added. Solution draining from the bottom of the column was pumped back to a 40 litre holding tank and then recirculated back to the

column. POT Chalcopyrite inoculum was used to start the column. After day 3 the column flooded and the column was switched to upflow flooded mode.

Column leach overflow was transferred to a 6" diameter by 2' height ferric  
5 regeneration column to convert the ferrous iron prior to metals recovery. The 1<sup>st</sup> stage column was operated at 50°C, pH 1.8 and a solution flow rate of 0.085 m<sup>3</sup>/hr/m<sup>2</sup> (11.0 ml/min). The 2<sup>nd</sup> stage regeneration column was operated at 45°C, pH 1.8 and the solution flow rate was determined depending on the rate of ferric regeneration. The column was operated for a period of 72 days. The pilot column  
10 and ferric regeneration test results are shown in Tables 9 and 10, respectively. Final metal extraction for Ni was 71.8%, Co 66.8%, Cu 59.6%, Fe 23.9% and S 18.4%.

15 **Table 9**  
**Pilot Column Test Results**

<b>Acid Leach:</b>	27.65L of Acidified H2O							
<b>Bio-Leach:</b>	27.65L of Acidified H2O							
<b>Feed:</b>	60.679 Kg (-4 mesh, 3.28% H2O, 58.689 kg dry weight)							
<b>Flow Rate:</b>	11ml/minh (hold up = 2.65L)							
<b>Operating pH:</b>	1.80							
<b>Temperature:</b>	50°C							
<b>Date</b>	<b>Day</b>	<b>ORP</b>	<b>Cum.</b>	<b>Fe</b>	<b>Ni</b>	<b>Co</b>	<b>Cu</b>	<b>S</b>
		<b>mV</b>	<b>Acid (ml)</b>	<b>(%)</b>	<b>(%)</b>	<b>(ppm)</b>	<b>(%)</b>	<b>(%)</b>
<b>Head Grade:</b>				<b>13.6</b>	<b>0.72</b>	<b>272</b>	<b>1.03</b>	<b>4.6</b>
				<b>Solution Assay Extraction</b>				
<b>Acid Leach</b>				<b>Fe</b>	<b>Ni</b>	<b>Co</b>	<b>Cu</b>	<b>S</b>
12/18/99	1	281	70	<b>(%)</b>	<b>(%)</b>	<b>(%)</b>	<b>(%)</b>	<b>(%)</b>
12/29/99	13		496	3.4	7.6	6.1	0.3	
01/04/00	19	364	1236	6.8	15.7	13.0	5.7	
01/06/00	21	361	1356	8.0	17.8	16.5	8.4	
01/10/00	25	369	1773	9.6	21.5	20.3	13.1	
01/13/00	28	362	2073	14.8	24.3	23.7	17.0	

01/17/00	29	366	2484	14.2	27.4	27.7	22.3	
01/18/00	30							
<b>Bio-Leach</b>								
01/20/00	2	367	2514	15.0	29.3	29.5	24.1	
01/22/00	4	Column flooded turned to upflow mode						
01/26/00	8	356	2614	16.7	34.6	32.9	30.8	
01/31/00	13	383	2714	16.6	40.3	38.9	37.0	
02/03/00	16	383	2755	15.3	39.6	39.0	36.5	
02/08/00	21	400	2787	15.8	49.8	47.5	44.4	
02/11/00	24	405	2797	15.4	52.8	53.4	46.8	
02/14/00	27	400	2807	14.9	55.8	55.5	48.4	
02/21/00	33	409	2832	14.0	59.7	56.0	50.1	
02/24/00	36	411	2857	14.0	61.1	58.8	51.7	
02/28/00	40	410	2877	13.6	67.4	58.1	53.8	
03/02/00	43	415	2912	12.9	65.6	62.3	54.9	
03/07/00	48	415	2983	13.4	69.6	60.2	54.7	
03/09/00	50	413	3008	13.6	68.9	63.6	54.2	
03/13/00	54	418	3061	13.9	69.5	63.8	55.0	
03/16/00	57	422	3101	13.8	70.9	67.4	55.1	
03/27/00	68	447	3216	13.7	73.6	65.9	55.7	
03/31/00	72		3216					
<b>Residue</b>	72			23.9	71.8	66.8	59.9	18.4

Table 10

## Ferric Regeneration Test Results

<b>Culture:</b>	For initial inoculation, a mixture of Inco, 40R1 and TC4 cultures were used										
<b>Feed:</b>	3000g Ceramic, 1.5L 40R1 +1.5L Pot 10k nutrient , 600 ml hold up, Ferric Regeneration Using Fe <sub>2</sub> SO <sub>4</sub> *7H <sub>2</sub> O (25 g/l)										
<b>Temp.:</b>	45°C		<b>pH:</b>	1.80							
<b>Date</b>	<b>Day</b>	<b>ORP</b>	<b>Fe<sup>2+</sup></b>	<b>ORP</b>	<b>Acid</b>	<b>Date</b>	<b>Day</b>	<b>ORP1</b>	<b>Fe<sup>2+</sup></b>	<b>ORP</b>	<b>Acid</b>
		<b>1</b>		<b>2</b>						<b>2</b>	<b>d</b>
		<b>mV</b>	<b>(g)</b>	<b>mV</b>	<b>(ml)</b>			<b>mV</b>	<b>(g)</b>	<b>mV</b>	<b>(ml)</b>
12/22/99	0	453			0.0	02/05/00	45	698			31.0
12/23/99	1	456			0.0	02/06/00	46	570			31.0
12/24/99	2	471			0.0	02/07/00	47	697	1L TC10	427	31.0
12/25/99	3	505			0.0	02/08/00	48	458			31.0
12/26/99	4	661	20	529	0.0	02/09/00	49	598			31.0
12/27/99	5	610	20	508	0.0	02/10/00	50	659	1L TC10	427	31.0
12/28/99	6	676	20	500	0.0	02/11/00	13 in. column		2L 0k		31.0
12/29/99	7	680	20		0.0	02/12/00	51	683			31.0
12/30/99	8	656	20	493	0.0	02/13/00	52	632			31.0
12/31/99	9	676	20	504	0.0	02/14/00	53	685	1L TC10	410	31.0

01/01/00	10	674	20	494	0.0	02/15/00	54	462			31.0
01/02/00	11	676	20	502	0.0	02/16/00	55	398	6L 9k		35.0
01/03/00	12	681	20	498	0.0	02/17/00	56	476			35.0
01/04/00	13	682	20	500	0.0	02/18/00	57	673	1L TC10	427	35.0
01/05/00	14	687	40	484	0.0	02/19/00	58	681	1L TC10		35.0
01/06/00	15	693	60	467	0.0	02/20/00	59	675			35.0
01/07/00	16	668	2L 9K	427	0.0	02/21/00	60	667	1L TC10	435	35.0
01/08/00	17	692	20	495	0.0	02/22/00	61	680	2L TC10	421	35.0
01/09/00	18	700	40	477	0.0	02/23/00	62	637	3L TC10	385	35.0
01/10/00	19	702	160	438	0.0	02/24/00	63	526			35.0
01/11/00	20	485			0.0	02/25/00	64	656			35.0
01/12/00	21	654	160	421	1.0	02/26/00	65	693	2L Fe 2+	411	35.0
01/13/00	22	485			1.0	02/27/00	66	620	2L Fe 2+	408	35.0
01/14/00	23	669	160	430	1.0	02/28/00	67	430			37.0
01/15/00	24	480			1.0	02/29/00	68	600	2L Fe 2+	397	41.0
01/16/00	25	494			1.0	03/01/00	69	491			41.0
01/17/00	26	621	160	460	1.0	03/02/00	70	641	2L Fe 2+	389	46.0
01/18/00	27	447			1.0	03/03/00	71	470			54.0
01/19/00	28	476			1.0	03/04/00	72	536			54.0
01/20/00	29	535			1.0	03/05/00	73	656			54.0
01/21/00	30	694	1L TC10		1.0	03/06/00	74	651	2L Fe 2+	441	61.0
01/22/00	31	525			1.0	03/07/00	75	444			61.0
01/23/00	32	502			1.0	03/08/00	76	660	2L Fe 2+	421	61.0
01/24/00	33	649	1L TC10	432	1.0	03/09/00	77	651	2L Fe 2+	406	66.0
01/25/00	34	457			1.0	03/10/00	78	634	2L Fe 2+	393	69.0
01/26/00	35	503			1.0	03/11/00	79				69.0
01/27/00	36	669	1L TC10	427	31.0	03/12/00	80	710	2L Fe 2+	390	69.0
01/28/00	37	459			31.0	03/13/00	81	439			69.0
01/29/00	38	518			31.0	03/14/00	82	641	2L Fe 2+	414	69.0
01/30/00	39	682			31.0	03/15/00	83	500			69.0
01/31/00	40	431	1L TC10	427	31.0	03/16/00	84	674	2L Fe 2+	416	79.0
02/01/00	41	448			31.0	03/17/00	85	616	2L Fe 2+	384	89.0
02/02/00	42	481			31.0	03/18/00	86	620	2L Fe 2+	405	89.0
02/03/00	43	678	1L TC10	426	31.0	03/19/00	87	515			89.0
02/04/00	44	458			31.0	03/20/00	88	662	2L Fe 2+	400	104.0

### Example III

Further testing was conducted on a pilot plant constructed in accordance with the first embodiment of the present invention and Figure 1, comprising a 5000 tonne  
5 heap composed of the Radio Hill disseminated ore referred to previously. Figure 4 shows the mass of ferric iron, ferrous iron and the total amount of iron within the liquor holding pond over a period of time. Two trend curves are shown added,

one showing a six day rolling average of ferrous iron A, the other, a six day rolling average of ferric iron B, present within the liquor holding pond.

Examination of the rolling average curve for ferric iron A shows three distinct periods over which ferrous conversion took place:

5

- Period 1 – 6/6/00 → 14/6/00
- Period 2 – 18/7/00 → 28/7/00
- Period 3 – 18/7/00 → 15/8/00

10 Period 1 was run at an irrigation rate of 100L/m<sup>2</sup>/h. Periods 2 & 3 varied between 10L/m<sup>2</sup>/hr and 50L/m<sup>2</sup>/hr. During Period 3 some interruptions to the system were experienced and it is expected that these would be taken into account when operating the ferric generator on an ongoing basis. These three periods can be used to evaluate the operation of the heap leach.

15 The masses of ferric and ferrous iron present in the pond have been extrapolated from the trend curves in Figure 4 to provide values of each iron moiety on the given dates, see Table II below. It is important to stress that these values do not account for the mass of iron held within the ore or waste heaps. It is assumed that any liquor in the waste heap is entirely ferric and the ore heap need not be  
20 included for the purposes of the rate calculation.

**Table II**

**Levels of ferrous and ferric iron present within the pond on the given dates, extrapolated from the rolling average curves.**

Date	Tonnes of Ferric	Tonnes of Ferrous
6/6/00	1.406	0.918
14/6/00	4.041	0.252
18/7/00	0.526	1.414
28/7/00	2.595	0.701
15/8/00	4.811	0.104

Examination of the rate curves during each period indicate that the rate of ferrous conversion appears to be higher during period 1 slightly lower during period 2 and the slowest for period 3. Since the levels of total iron in solution were highest during period 1 this suggests that high levels of total iron in solution do not  
5 hamper the rate of ferrous iron conversion.

Examination of the iron conversion rates over period 1 and 2 and 1 and 3, indicates that a slight variation is present and this appears to be dependant on the irrigation rate of the feed solution.

Table 12 below illustrates the conversion rates over the three periods defined at  
10 the various flow rates for each period. The flow rates quoted below are averaged over each period of time.

**Table 12**

**Rates of Ferric conversion at different flow rates**

Date	Tonnes Ferric	Flow rate l/m <sup>2</sup> /hr	Elapsed Time (days)	Heap Tonnes	Ferric Conversion kg/hr	Conversion Rate g/hr/tonne waste rock
8/06/00	1.406	100	8	3740	13.72	3.67
14/06/00	4.041	100		3740		
Diff	2.635					
18/07/00	0.526	65	10	3740	8.62	2.30
28/07/00	2.595	65		3740		
Diff	2.069					
18/07/00	0.526	50	28	3740	6.38	1.70
15/08/00	4.811	50		3740		
Diff	4.285					

15 It is important to note that no account has been made of any iron that precipitates in the ferric generating heap and it is highly likely that the ferrous conversion rates are in fact significantly higher than those noted in Table 12. The results suggest that the maximum capacity of the heap lie at a flow rate either above 100L/m<sup>2</sup>/h or between 65L/m<sup>2</sup>/h and 100L/m<sup>2</sup>/h. The results indicate that on a given heap the  
20 rate of ferrous conversion is dependent on the irrigation rate of the heap. The



total levels of iron in solution appear to have no detrimental effect on the rate of iron conversion.

Figure 5 describes the rate of recovery of nickel from the ore heap of Example III.

Modifications and variations such as would be apparent to the skilled addressee  
5 are considered to fall within the scope of the present invention.

## Claims

1. A bacterially assisted heap leach characterised by the steps of:
  - providing an ore heap to oxidise sulphide minerals therein;
  - providing a biological contactor inoculated with ferrous iron oxidising bacteria;
  - providing at least one leach solution pond to feed solution to, and receive leach solution from both the heaps; and
  - bleeding a portion of the leach solution and passing same to a means for metals recovery.
2. A bacterially assisted heap leach according to claim 1 characterised in that one or both of the heaps are aerated at or near a base thereof.
3. A bacterially assisted heap leach according to claim 1 or 2 characterised in that the biological contactor is provided in the form of a second heap.
4. A bacterially assisted heap leach according to claim 3 characterised in that the second heap is formed of relatively inert waste rock.
5. A bacterially assisted heap leach according to any one of the preceding claims characterised in that the second heap is inoculated with *Thiobacillus ferrooxidans* or similar bacteria.
6. A bacterially assisted heap leach according to any one of the preceding claims characterised in that the bled leach solution is taken from the second heap.
7. A process for the recovery of nickel and other base metals from sulphide ores or fractions thereof, the process characterised by the steps of:

oxidising the sulphide ore in a heap leach to produce a leach solution;  
and

oxidising any ferrous iron in the leach solution from the heap leach  
prior to recovery of base metals therefrom.

- 5    8.    A process according to claim 7 characterised in that the oxidation of the  
sulphide ore or fraction thereof is achieved through the action of  
chemolithotrophic bacteria.
9.    A process according to any one of claims 7 to 8 characterised in that the  
oxidation of ferrous iron in the leach solution is achieved by passing same  
10    through a further heap inoculated with an iron oxidising bacteria.
10.   A process according to claim 9 characterised in that the further heap is  
formed of relatively inert waste rock.
11.   A process according to any one of claims 7 to 10 characterised in that the  
leach solution is recycled more than once through the heap to increase the  
15    level of dissolved metals therein.
12.   A process according to any one of claims 7 to 11 characterised in that at  
least a proportion of the ferric iron in the leach solution is precipitated by  
hydration.
13.   A process according to claim 12 characterised in that the precipitation of  
20    iron in the leach solution forms jarosite or goethite, and acid.
14.   A process according to claim 12 or 13 characterised in that the precipitation  
of iron occurs in the waste rock heap.

FIGURE 1

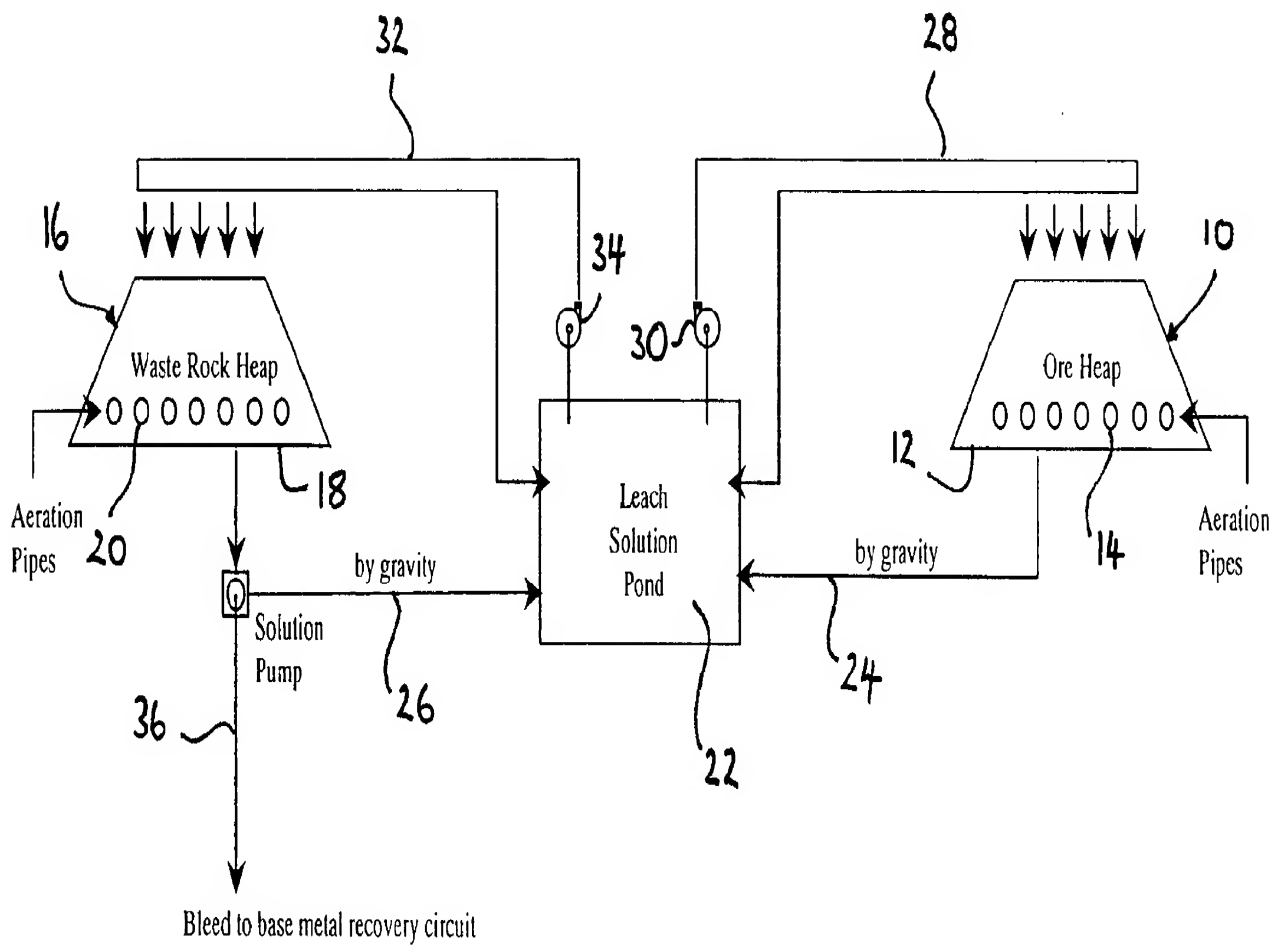


FIGURE 2

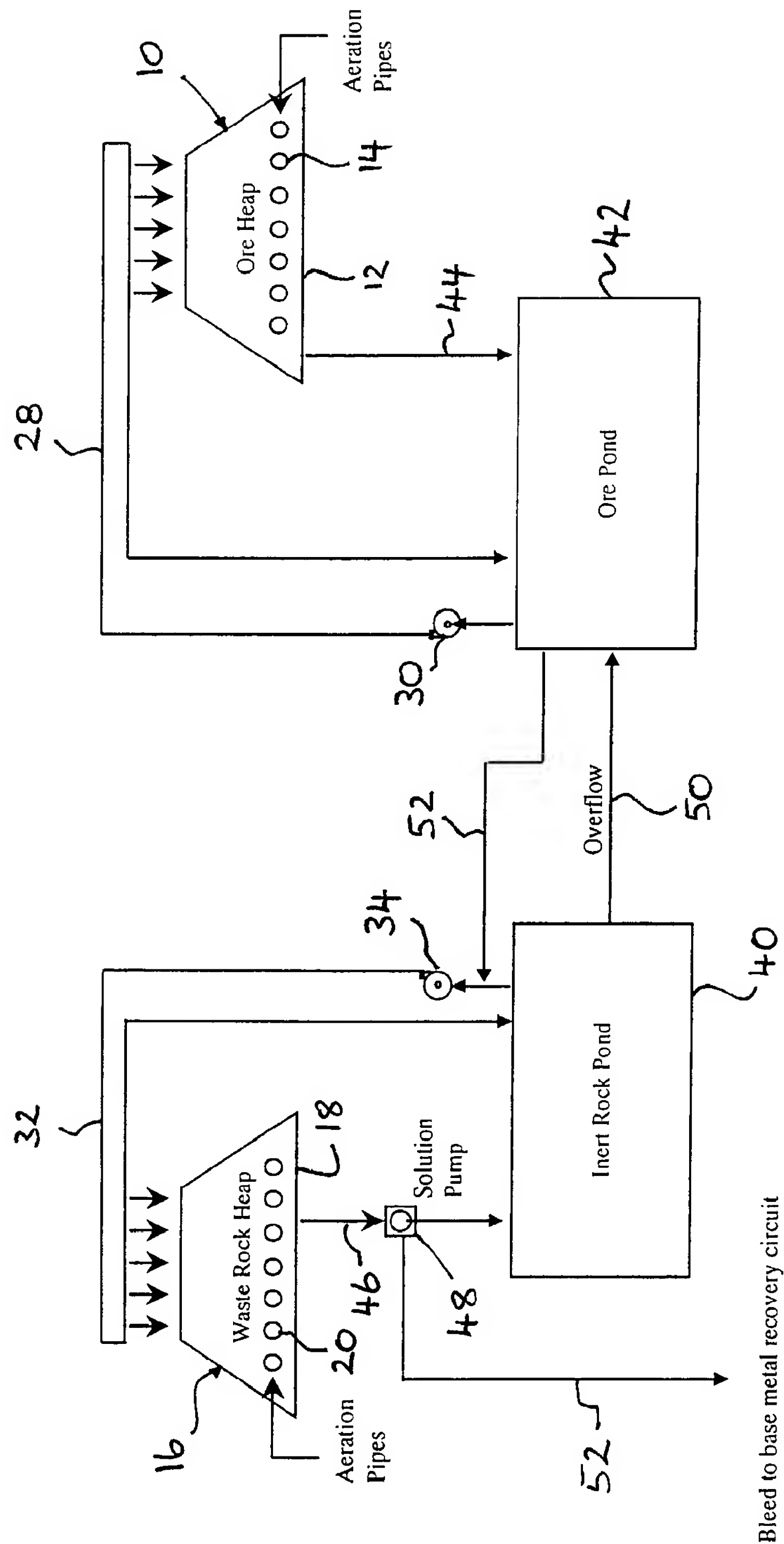


Figure 3

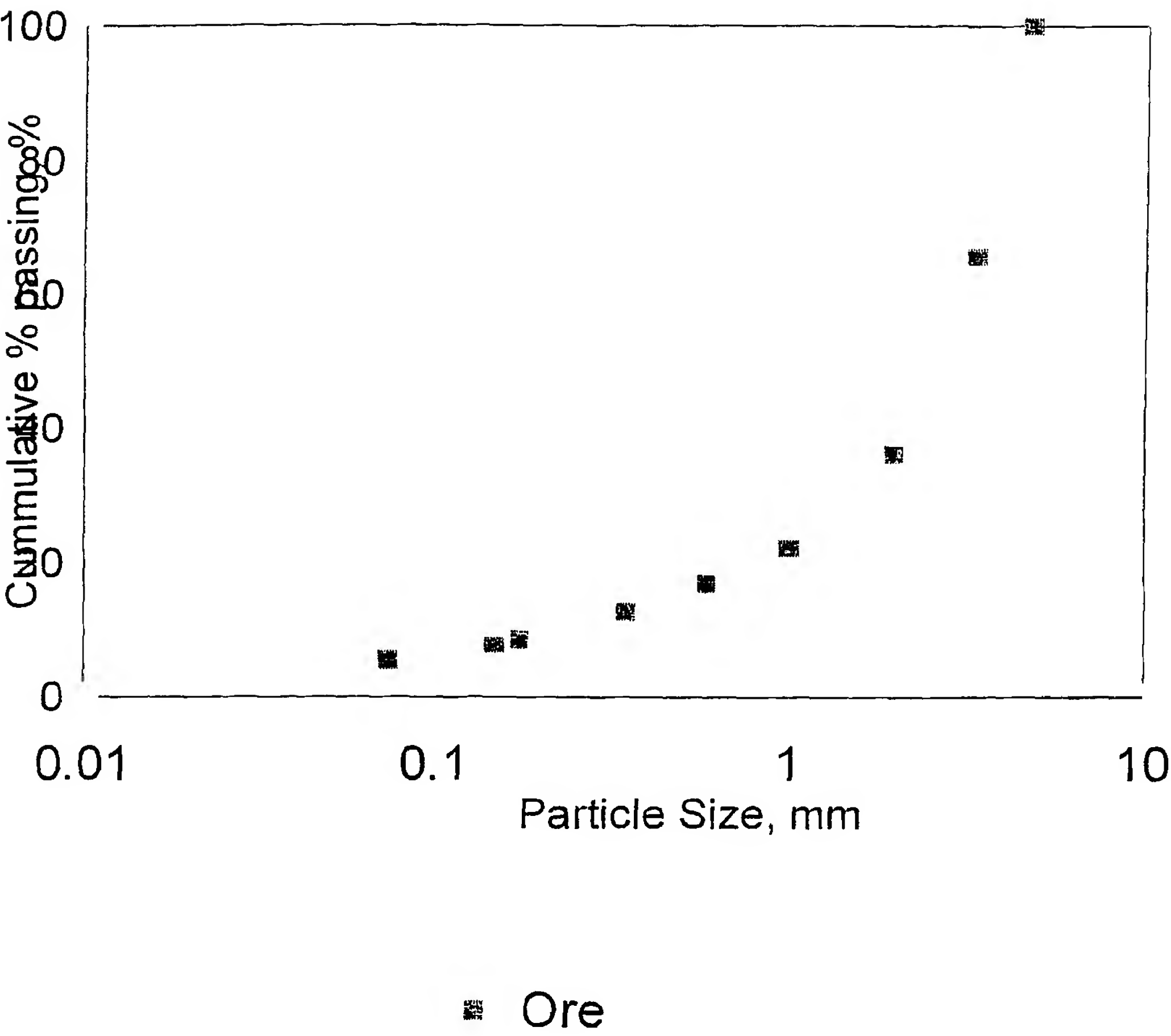
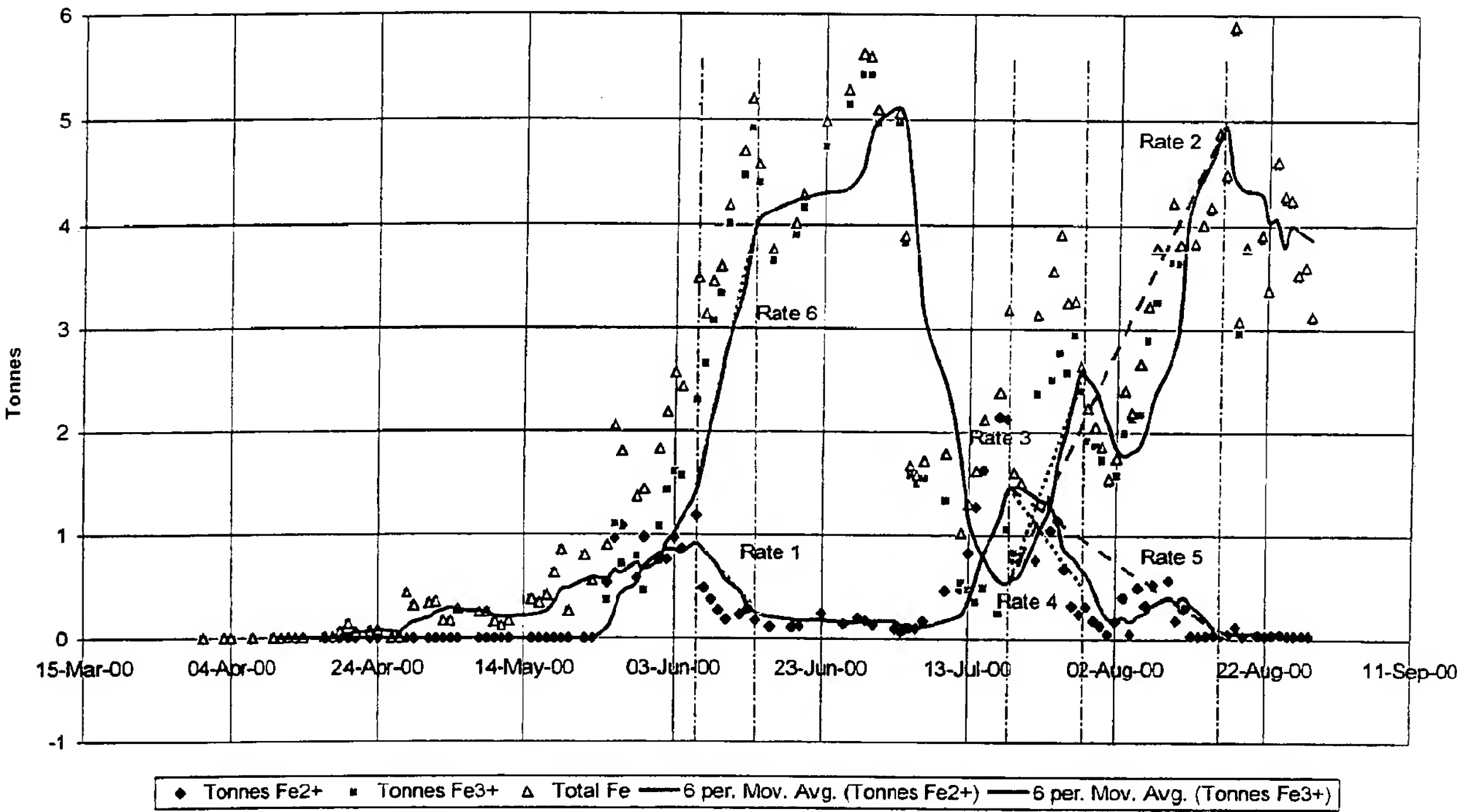




Figure 4



Nickel Recoveries (by Week)

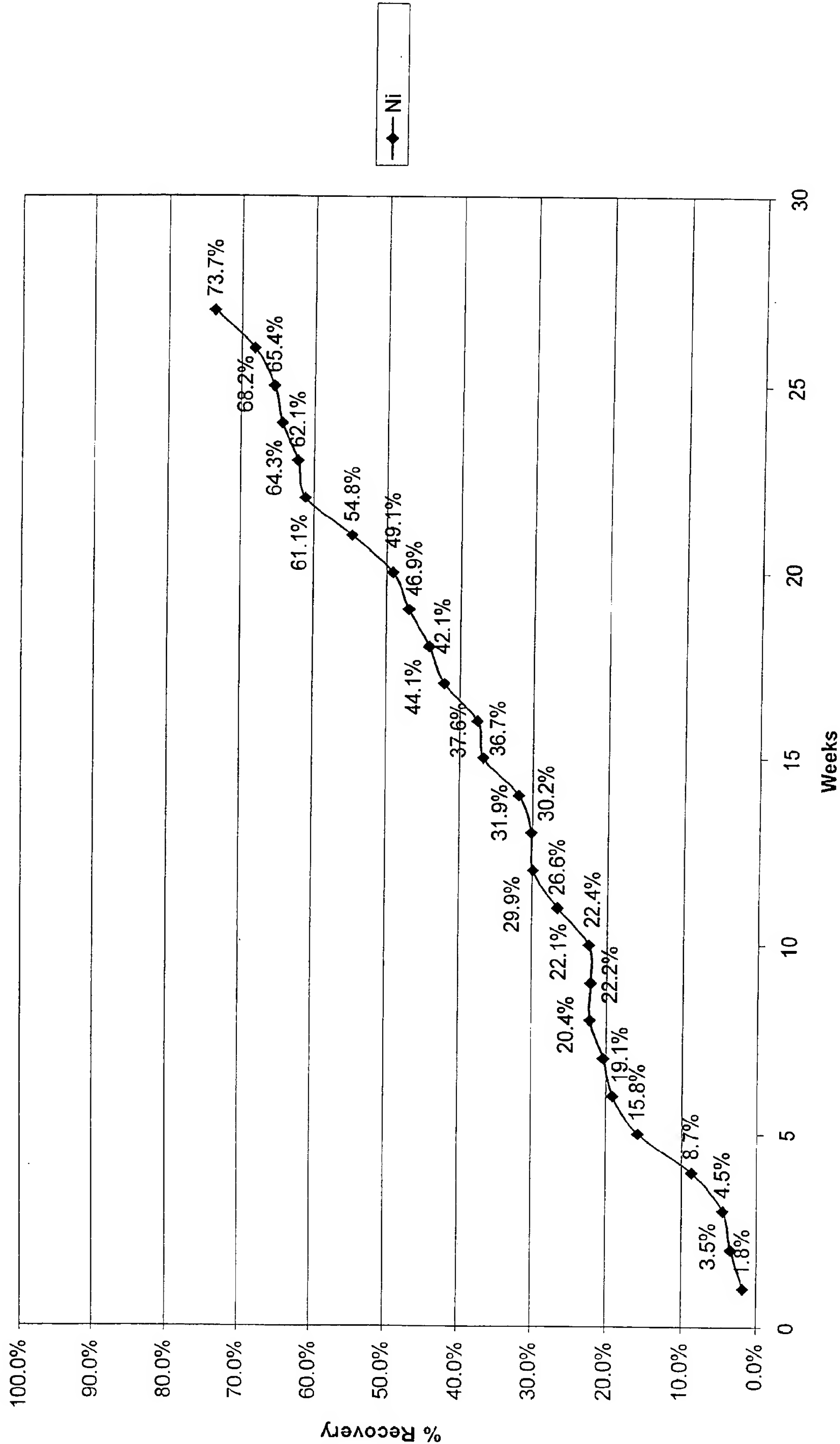



FIGURE 5

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU00/01437

<b>A. CLASSIFICATION OF SUBJECT MATTER</b>												
Int. Cl. <sup>7</sup> : C22B 3/18, 3/04, 3/06, 23/00												
According to International Patent Classification (IPC) or to both national classification and IPC												
<b>B. FIELDS SEARCHED</b>												
Minimum documentation searched (classification system followed by classification symbols) IPC <sup>7</sup> AS ABOVE												
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched												
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used) Derwent WPAT: IPC <sup>7</sup> as above and oxidi+ and Bacter+												
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>												
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.										
X	WO 9612826 A1 (Geobiotics Inc) 2 May 1996 Whole Document	1 to 14										
X	WO 9638381 A1 (Geobiotics Inc) 5 December 1996 Whole Document	1 to 14										
X	EP 522978 A1 (Newmont Mining Corp) 13 January 1993 Whole Document	1 to 14										
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C <input checked="" type="checkbox"/> See patent family annex												
<p>* Special categories of cited documents:</p> <table border="0"> <tr> <td>"A" document defining the general state of the art which is not considered to be of particular relevance</td> <td>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</td> </tr> <tr> <td>"E" earlier application or patent but published on or after the international filing date</td> <td>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone</td> </tr> <tr> <td>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</td> <td>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art</td> </tr> <tr> <td>"O" document referring to an oral disclosure, use, exhibition or other means</td> <td>"&amp;" document member of the same patent family</td> </tr> <tr> <td>"P" document published prior to the international filing date but later than the priority date claimed</td> <td></td> </tr> </table>			"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention	"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone	"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art	"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family	"P" document published prior to the international filing date but later than the priority date claimed	
"A" document defining the general state of the art which is not considered to be of particular relevance	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention											
"E" earlier application or patent but published on or after the international filing date	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone											
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art											
"O" document referring to an oral disclosure, use, exhibition or other means	"&" document member of the same patent family											
"P" document published prior to the international filing date but later than the priority date claimed												
Date of the actual completion of the international search 15 January 2001		Date of mailing of the international search report 17 January 2001										
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaaustralia.gov.au Facsimile No. (02) 6285 3929		Authorized officer  DAVID K. BELL Telephone No : (02) 6283 2309										

INTERNATIONAL SEARCH REPORT

International application No.  
PCT/AU00/01437

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	AU 9918524 A1 (Placer Dome Inc) 16 September 1999 Whole Document	1 to 14

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International application No.  
**PCT/AU00/01437**

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report				Patent Family Member			
WO	9612826	AU	39603/95	BR	9509472	CA	2203258
		GB	2308589	NZ	295938	ZA	9509037
		US	5688304	US	5779762	US	6086656
WO	9638381	AP	613	AU	61450/96	BG	102099
		BR	9608992	CA	2222900	CN	1191521
		EP	885170	HU	9900904	NZ	310627
		PL	323668	US	5766930	US	6159726
		US	6083730	US	5676733	US	6146444
		US	6107065	AU	12981/95	BR	9408248
		CA	2176147	FR	2713242	GB	2298643
		NZ	277674	US	5431717	WO	9515403
		ZA	9409538	US	5611839	US	5800593
		US	5573575				
EP	522978	AU	18687/92	BR	9202534	CA	2073589
		MX	9203974	TR	26634	US	5332559
		ZW	106/92	US	5834294	ZA	9204825
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END OF ANNEX							